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Influence of moisture on the growth and biomass allocation in *Haloxylon ammodendron* and *Tamarix ramosissima* seedlings in the shelterbelt along the Tarim Desert Highway, Xinjiang, China

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The authors studied the effects using three different levels of irrigation on the growth and biomass allocation in *H. ammodendron* and *T. ramosissima* seedlings in the shelterbelt along the Tarim Desert Highway. The three irrigation amounts were 35 (CK), 24.5 (treatment 1), and 14 (treatment 2) kg·ind. plant^{-1}·once^{-1}, respectively. The results show that (1) the vertical depth of the two seedlings' root increased with lower levels of irrigation showing that the two species adapted to decreased irrigation by root elongation in the hinterland of the Taklimakan Desert, and the vertical root depth of *H. ammodendron* under treatment 2 was notably higher than CK. (2) Compared with CK, the belowground biomass of treatment 1 and 2 both showed a significant increase as follows: *H. ammodendron* seedlings increased by 14.51% and 37.03% under treatment 1 and 2, respectively, while *T. ramosissima* seedlings increased by 68.19% and 25.78% under treatment 1 and 2, respectively. This means that *H. ammodendron* seedlings were more adapted to the conditions in treatment 2 while *T. ramosissima* seedlings were better adapted to treatment 1 conditions. (3) When compared with CK, the fine root bomass of these two species all exhibited some increase under both treatments, and ANOVA analysis showed that the biomass of deep layer root of the two species under treatment 2 was notably higher than CK and treatment 1. This should help seedlings to more effectively absorb soil water from deep layers during dry conditions. (4) The root-shoot ratio was different for these two species. For *H. ammodendron* seedlings, the root-shoot ratio was less than 1, while for *T. ramosissim* seedlings it was larger than 1. The root-shoot ratio of *H. ammodendron* seedlings increased with decreasing levels of irrigation, and that of *T. ramosissim* seedlings also increased under treatment 2. (5) With decreasing levels of irrigation, due to the difference of species, the growth variation of aboveground indexes was also different, while compared with CK, it was not significant.

Haloxylon ammodendron, *Tamarix ramosissima*, belowground biomasses, root-shoot ratio

Plants can adapt to environmental changes by adjusting allotment of resources. Roots are the first organ which changes their growth patterns under the condition of abiotic adversity-stress. Plants can make the relevant responses under stressful conditions. At the beginning, a plant can adjust its the gene expression on temporal-spatial scales; and then, it changes the direction of metabolic pathways, which in turn changes the distribution proportion of carbohydrate accumulation, and thus

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changes the root morphology and distribution to accommodate the change of environment condition[1]. The availability of water is the main factor affecting the survival, growth, reproduction, and distribution of plants. In an arid desert area plants may be exposed to long-term drought conditions because of the huge deficit between precipitation and potential evapotranspiration. A reduced supply of water is the major threat to plants in arid and semi-arid regions.

Therefore, studying the effect of a reduced water supply on plants is critical in understanding the physiological ecology in this region's adverse ecological conditions.

The measurement of biomass provides the basic data for researching net primary productivity. This measurement gives a favorable scale for estimating the carbon pool captured by vegetation as well as providing an important parameter for evaluating structure and function of ecosystem. Biomass is important in the study of nutrients allocation and carbon cycle in ecology system[2,3]. Plants can always adjust their growth strategy and biomass allocation to accommodate environmental changes during various growth stages. Under the conditions of decreasing water supply, plants will minimize stress injury by changing biomass allocation to accommodate this environment stress[4]. After the establishment of the shelterbelt along the Tarim Desert Highway, this shelterbelt has been irrigated with ground water. How can the desired functions of stability and sustainability of the shelterbelt along the Tarim Desert Highway be maintained while minimizing its impact on limited water resources when one considers the fact that the shelterbelt is expected to remain in place indefinitely? Research can help answer this question. Existing experiment information about how plants adjust growth and biomass allocation under reduced water availability remains insufficient. Current irrigation management of the shelterbelt along the Tarim Desert Highway has not tested changes in water availability. We tested several different levels of irrigation for this experiment and discussed the resulting impacts on plant growth and biomass allocation, which helps reveal tested plant's mechanisms in reaction to drought and its drought-resistance[5].

1 Materials and methods

1.1 Natural conditions of the research site

The experiment was conducted in an area of lowland dunes, 8 km away from the southeastern Taklimakan Desert Botanical Garden of Xinjiang Ecology and Geography Institute, CAS. Weather data was obtained from the Taizhong Meteorological Station and the Auto-Meteorological Station of the Botanical Garden. The annual average temperature is 12.4℃. July, the hottest month in a year, has an average temperature of 28.2℃, while December, the coldest, has an average temperature of −8.1℃. The recorded high temperature is 45.6℃ and the low one −22.2℃. The sun shines about 2 571.3 hours a year. The mean annual precipitation is 36.6 mm, and the average relative humidity is 29.4%. The potential evapotranspiration rate is 3 638.6 mm. The average wind speed there is 2.5 m/s, while the highest 24.0 m/s. From April to August is the windy season with an average wind velocity of 3.2 m/s. Sandstorms occur frequently. An average year has 60 days with heavy wind, 74 days with blowing dust, and 45 days with blowing windborne sand. In different physiognomy, soil has different features. Salinity ranges from 1.26 to 1.63 g/kg. The subsoil is occasionally semi-clay usually only 20—60 cm thick, below the windborne sandy soil.

1.2 Experimental materials

The two species, *H.ammodendron* and *T. ramosissima*, both dominating the shelterbelt along the Tarim Desert Highway were selected for study. The experiments were run on one-year-old seedlings taken from Taklimakan Botanical Garden.

1.3 Experimental methods

(i) Experimental designs and treatments. In March 2005, 120 individuals of *H.ammodendron* and *T. ramosissima* seedlings each were planted in a 5 100 m^2 experimental site (85 m × 60 m). The individuals were planted in a grid at intervals of 4 m. Seedlings were selected in an attempt to use seedlings of similar size and vigor, and then underground portion was sheared to the same length before they were transplanted. Drip irrigation was used for 10 d from March to August and 15 d from September to November. For preventing the seedlings from being buried in sand, we set up mechanical sand barrier between every two rows of seedlings. Two species were all tested using three different water supply patterns. The seedlings were all watered using different amounts of water in each treatment as follows: (1) 35 $kg \cdot ind.plant^{-1} \cdot once^{-1}$ of water, consistent with the amounts currently used in irrigation along the shelterbelt of the Tarim Desert Highway; we called this treatment "CK" since it is the control or check level of irrigation; (2) experimental treatment 2, using 14 kg·ind.plant^{-1}·once^{-1} of water, based on a former water consumption test; and (3) treatment 1, using 24.5 kg·ind.plant^{-1}·once^{-1} of water, an intermediate amount of water. One month after planting, we checked the survival rates. All plants exhibited a survival rate of about 90%. For *H. ammodendron*, the average plant height, basal stem diameter, and crown dia- meter were 51.63 cm, 3.35 cm, and 87.66 cm^2, respectively; but for *T. ramosissima* those were 66.05 cm, 5.99 cm, 275.44 cm^2, respectively.

(ii) Sampling and measurement. After seven months growth, the aboveground growth indexes and biomass of *H. ammodendron* and *T. ramosissima* were checked in October 2005. Four plants from each treatment were selected randomly, and plant height, basal stem diameter, and crown diameter were measured using a tape ruler and vernier caliper. The sample was then placed in a plastic bag. To study root distribution, a digging method was used to take the plant as a center, with every 30 cm as a diameter on the horizon direction and every 20 cm as a layer in the vertical direction, and then sieve the root out until no root exists in a sieve with 2 mm diameter. At the same time, the maximum depth of root length and lateral root growth length were measured on the spot. The root samples were then dividend into fine root (diameter ≤1 mm) and coarse root (diameter >1mm). The samples of above- and underground plant portions were dried at 105℃ until the weights of samples no longer changed; then the samples were weighed.

(iii) Data analysis. ANOVA was used to detect differences among the treatments using software package of SPSS (11.0).

2 Results and analysis

2.1 Growth of shelterbelt seedlings using different irrigation amounts

The two test species exhibited complex growth index feedback in their adaptation to the level of irrigation (Table 1). When irrigation amounts decreased, individual plant height of *H. ammodendron* seedlings was decreased, in direct proportion to the level of irrigation. The decrease of growth under treatment 1 and 2 were 5.28% and 7.26%, respectively. The results indicated that the decrease of irrigation amounts limited seedling height in *H. ammodendron*. This result agrees with Xiao's[4], who found a similar response in seedlings of *Pinus koraiensis*, *Fraxinus mandsurica*, *Juglans mandshurica*, *Tilia amurensis* where limited irrigation amounts limited individual plant height. However, with a decreased level of irrigation plant height of *T. ramosissima* seedlings slightly increased. This result is probably due to low sample size. The study of variance analysis of the CK treatment revealed that individual plant height of *H. ammodendron* (F=0.500, P=0.623) and *T. ramosissima* seedlings (F=1.389, P=0.298) were not significantly different in treatment 1 and 2. No significant difference was found between treatment 1 and 2. This indicated that individual seedlings height of two species is not sensitive to the changes of water supply at this location. With decreased irrigation amounts, vertical depth of root of *H. ammodendron* and *T. ramosissima* seedlings increased. The increase of vertical root depth of *H. ammodendron* seedlings in treatment 1 and 2 are 6.67% and 39.29%, respectively. The results of variance analysis (F=3.25, P=0.086) revealed no significant difference between treatment 1 and CK. But the vertical depth of root in treatment 2 is significantly deeper than CK. Increase of root vertical depth of *T. ramosissima* seedlings in treatment 1 and 2 is 7.69% and 30.77%, respectively. But the vertical depth of root has no significant difference in different irrigation amounts (F=1.67, P=0.171). Table 1 shows that crown diameter of two species differed. The crown diameter of *H. ammodendron* seedlings in treatment 1 and 2 was smaller than CK. In *T. ramosissima* the opposite occurred. The results of variance analysis showed that crown diameter of *H. ammodendron* (F=0.165, P=0.850) and *T. ramosissima* seedlings (F=0.359, P=0.708) was no significantly different. Compared with CK, basal stem diameter of *H. ammodendron* and *T. ramosissima* seedlings was increased in both treatment 1 and 2. It is likely that their root system was well developed, so the plants could collect more water and nutrients and produce a thick growth. However, the result of variance analysis showed that basal stem diameter of *H. ammodendron* (F = 0.019, P = 0.982) and *T. ramosissima* seedlings (F = 1.836, P = 0.214) was no significantly different in different treatments. This indicated that the basal stem diameter of two species seedlings did not change based on water availability.

The dry weight of the root system is one of the most important indexes in the analysis of root system growth. It reflects the relationship between root system growth

Table 1 Change of two seedlings growth indexes depending on water availability[a)]

Species	Treatment	Plant height (cm)	Root depth (cm)	Crown diameter (cm^2)	Basal diameter (mm)	Above ground dry weight (g)	Root dry weight (g)
H. ammodendron	CK	75.75±3.79 a	70.00±10.00 b	5389.50±1046.62 a	12.77±3.43 a	115.57±36.44 a	101.48±36.72 a
	Treatment 1	71.75±2.87 a	75.00±9.57 ab	4677.00±981.01 a	13.33±0.89 a	135.74±27.77 a	116.20±16.66 a
	Treatment 2	70.25±5.09 a	97.50±25.00 a	4835.50±698.05 a	13.17±0.93 a	161.21±29.92 a	139.06±23.03 a
T.ramosissima	CK	71.50±7.56 a	65.00±5.00 a	1295.75±358.29 a	8.90±0.93 a	27.17±6.32 b	42.25±13.37 b
	Treatment 1	83.75±2.39 a	70.00±5.77 a	1780.00±385.94 a	10.96±0.73 a	54.46±5.76 a	71.06±9.02 a
	Treatment 2	86.00±8.29 a	85.00±9.57 a	1604.50±473.85 a	9.12±0.85 a	34.04±6.56 b	53.14±6.72 ab

a) The letters after the numbers shown in the table indicate their results of multiple comparisons. The numbers followed by different letters indicate that they are significantly different at 0.05 levels, otherwise, they are not significantly different at 0.05 levels (the same below).

and environment[6]. With lower irrigation levels, belowground biomass of two species increased. Compared with CK, the maximum of underground biomass of *H. ammodendron* seedlings appeared in treatment 2, which was 22.5% higher when compared with treatment 1. This indicated that the adaptability of *H. ammodendron* seedlings to the treatment 2 was perfect. However, underground biomass of *T. ramosissima* seedlings with treatment 1 was significantly higher than that with CK, which was 42.41% more than that of treatment 2. This indicated that the adaptability of *T. ramosissima* seedlings to treatment 1 was perfect.

2.2 Biomass allocation of two kinds of shelterbelt species seedlings under different irrigation amounts

(i) Aboveground biomass. Figure 1 shows the effect of water availability on the aboveground biomass of the two species. This figure shows that the aboveground biomass of *T. ramosissima* seedlings was significantly lower than *H. ammodendron* in all the three treatments, suggesting that *H. ammodendron* grows faster than *T. ramosissima* early in the seedlings stage. This may be attributed to the difference in the photosynthetic pathway of two species. *H. ammodendron*, a C_4 plant, has relatively strong photosynthetic capacity facilitating the accumulation of aboveground biomass, while *T. ramosissima,* a C_3 plant, has relatively weak photosynthetic capacity. Accordingly, the assimilation of aboveground biomass in *T. ramosissima* is relatively smaller than that of *H. ammodendron* under the same environmental conditions.

The aboveground biomass accumulation of the two species showed an apparent difference with decreased supply of water. The aboveground biomass of *H. ammodendron* seedlings tended to increase with the decline of water supply, and in contrast with CK, the aboveground biomass of treatment 1 and 2 increased by 17.46% and 39.49%, respectively. The strong root system of *H. ammodendron* may account for this as the root system should facilitate the acquisition of water and nutrients and eventually facilitate the growth of branches. The results of variance analysis (F=0.524, P=0.609) revealed that there was no significant difference among the aboveground biomass of *H. ammodendron* in each treatment; we conclude that aboveground biomass of *H. ammodendron* is not sensitive to water availability within the parameters measured. Compared with CK, aboveground biomass of *T. ramosissima* seedlings increased in both treatment 1 and 2, or 100.43% and 25.29%, respectively.

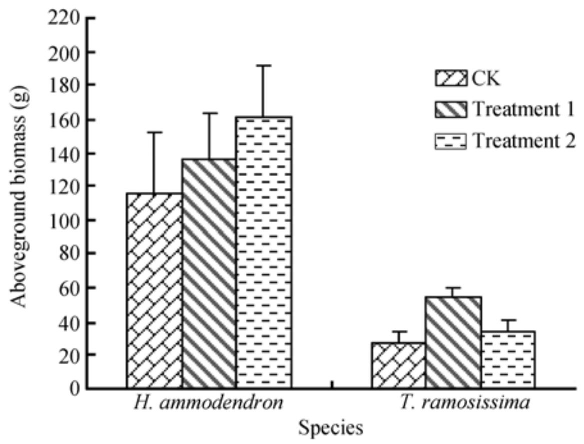

Figure 1 Effect of water conditions on the aboveground biomass of different species.

The results of variance analysis (F=5.205, P=0.031) showed the aboveground biomass of treatment 1 significantly higher than those of treatment 2 and CK, which means that *T. ramosissima* grows best under the water supply condition of treatment 1 .

(ii) Belowground biomass and its distribution pattern. Plant roots absorb soil water, when water availability changes, plant roots respond by emitting a chemical signal which causes the plant to initiate a series of responses to the change in water availability. At the same time, adaptive changes in root shape and structure and biomass occur[7]. Figure 2 shows that the underground biomass of *H. ammodendron* seedlings was significantly higher than *T. ramosissima* seedlings in all treatments. This reveals why the effective root density of *H. ammodendron* seedlings is three times higher than that of *T. ramosissima* seedlings under the same hydrologic conditions in the experimental area[8]. Compared with CK, the underground biomass of *H. ammodendron* seedlings under treatment 1 and 2 increased by 14.51% and 37.03%, respectively. This pattern demonstrates that *H. ammodendron* seedlings undergo soil aridity by its strong root system, showing adaptability to the deficit of soil water to some extent. In contrast, the underground biomass of *T. ramosissima* seedlings under treatment 1 and two also showed an increase when compared with CK; the underground biomass of *T. ramosissima* seedlings under treatment 1 increased by 68.19%, while in treatment 2 it increased by only 25.78%. It can be inferred that, in order to adapt the changes of water condition, the seedlings of *T. ramosissima* also expanded water availability by enhancing the branching and depth of its root growth when the water supply decreased. But *T. ramosissima* showed the greatest adaptability under treatment 1. Under treatment 2, the growth of roots of *T. ramosissima* seedlings was constrained to some extent; the dry matter accumulation was also less than under treatment 1, resulting in lower belowground biomass.

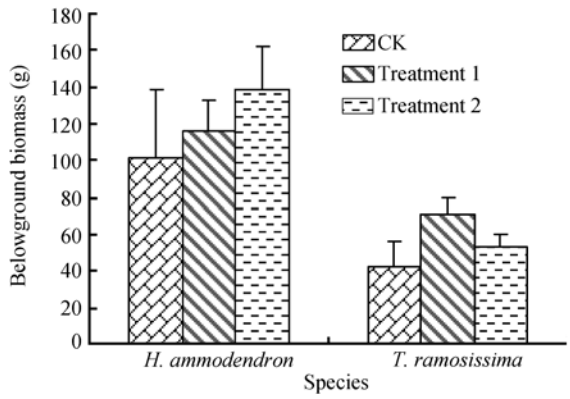

Figure 2 Effect of water availability on the belowground biomass of the experimental species.

The underground biomass of seedlings of *H. ammodendron* and *T. ramosissima* in treatment 2 was significantly higher than those of CK and treatment 1 at depths of 60—80 cm and 80—100 cm (Table 2); the underground biomass of two species at the layer of 0—60 cm has no significant different in every water supply level, which suggests that the seedlings of two species adapted to the water decline were mainly caused by an increase of deep layer root.

The observed root biomass at different depths in seedlings root of *H. ammodendron* and *T. ramosissima* were inverted pyramid-shape at every water supply level. As water supply declines, the spatial range and number of roots at the bottom of inverted pyramid-shape increases compared to CK. Namely, under current irrigation management, the roots of the plants comprising the shelterbelt along the Tarim Desert Highway form a larger proportion of their biomass in upper layer while downward root growth is low. In order to obtain more water and maintain growth and development with a reduction of water supply downward and outward root growth increase which increases the space the root occupies, deep root biomass increases along with the capability of absorbing deep soil water to make the plant more resistant to drought.

This is similar to *Sabina vulgaris* which adapts to a water deficit environment by increasing the depth of roots, offsetting the deficit of soil water[9]. This agrees with Wu's experiment[10], which found lower water availability promotes increased root length in winter wheat grow. That study indicates the plants in the shelterbelt along the Tarim Desert Highway which tolerate the intensive evaporation and rare precipitation rate, can keep the water balance in plants by increasing their downward root growth which increases absorption of the deep layer soil water[11] in order to offset the soil water deficit.

(iii) Biomass distribution in fine root and coarse roots. Roots can be divided into fine and coarse roots, each of

Table 2 Distribution of underground biomass of two desert species in each vertical layer with three different levels of water availability, measured in grams

Species	Treatment	0—20 (cm)	20—40 (cm)	40—60 (cm)	60—80 (cm)	80—100 (cm)
H. ammodendron	CK	41.65±12.61 a	29.77±14.15 a	24.53±11.40 a	5.54±3.19 b	0.00±0.00 b
	Treatment 1	50.26±8.46 a	41.10±8.75 a	20.97±8.56a	3.60±3.13 b	0.28±0.275 b
	Treatment 2	43.48±11.60 a	28.57±2.73a	28.87±4.72 a	29.77±9.00 a	8.36±3.59 a
T. ramosissima	CK	27.31±7.22 a	11.90±5.77 a	2.99±1.18 a	0.06±0.06 a	0.00±0.00 b
	Treatment 1	45.78±1.59 a	21.78±7.47 a	3.17±1.63 a	0.33±0.19 a	0.00±0.00 b
	Treatment 2	25.46±4.95 a	13.47±2.19 a	8.43±1.66 a	4.10±2.18 a	1.40±1.34 a

which has a different function. For the herbaceous plants and shrub, coarse roots are those with a diameter larger than 1mm, its primary function is water uptake and nutrients delivery; roots with a diameter smaller than 1mm are fine roots, their primary function is water transport and nutrient absorption[12]. Figure 3 compares CK with the two treatments, showing that the growth of two species seedlings' fine roots was greatly accelerated under treatment 1 and 2. Fine roots biomass of *H. ammodendron* and *T. ramosissima* seedlings increased by 31.46% and 44.63% under treatment 1, respectively, but increased by 80.67% and 30.38% under treatment 2, respectively. This increase in fine roots is certainly beneficial to plants in absorption and utilization of soil water providing an adaptation to the arid condition. This indicated that these two plants have a strong drought- resistant ability, but *H. ammodendron* seedlings adaptation to treatment 2 was better than to the other two treatments while *T. ramosissima* seedlings were better adapted to the conditions of treatment 1. This agreed with the former results. Figure 4 documents that when irrigation amounts decrease, the coarse root biomass of *T. ramosissima* seedlings was comparable to its total belowground biomass (Figure 2) and fine root's biomass (Figure 3), but the tendency of coarse root biomass of *H. ammodendron* seedlings was not consistent with its total underground biomass and fine roots as irrigation amounts decreased. Compared with CK, the biomass of coarse root was lower under treatment 1.

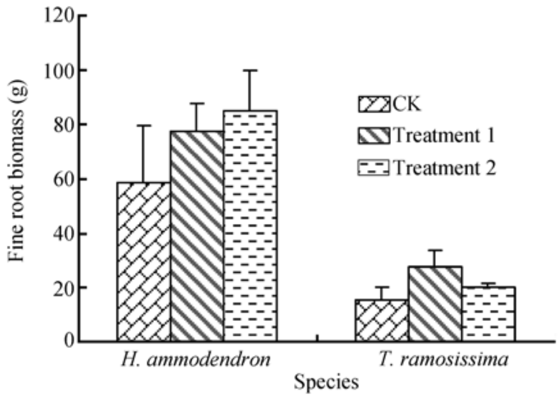

Figure 3 Effect of water availability on the fine root biomass of the studied species.

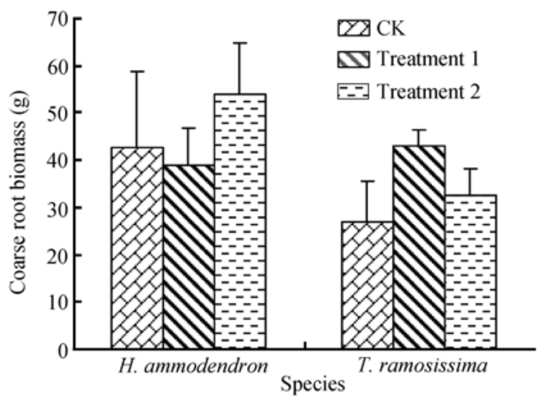

Figure 4 Effect of water availability on the coarse root biomass the studied species.

The proportion of fine root biomass and total biomass for both species was analyzed under different water supply conditions. The results revealed this ratio of fine root to total biomass in *H. ammodendron* seedlings was 57.89%, 66.46%, and 61.10% under CK, treatment 1, and treatment 2, respectively, but the proportion of *T. ramosissima* seedlings was 36.62%, 39.33%, and 37.96%, respectively. This shows that the water absorptivity of *H. ammodendron* was stronger than that of *T. ramosissima* in the seedlings growth stage under the same conditions of water availability, which makes seedlings of *H. ammodendron* more robust than those of *T. ramosissima*.

2.3 Root-shoot ratio

Huston[13] and Tilman[14] suggested that the ratio of below/above-ground biomass could reflect a plant's response to an environment factor. As for nursery stock, if the ratio of below/above-ground biomass is larger than 1, it indicates that the plant has an increased requirement and ability to use and capture water and nutrients. Figure 5 indicates that root-shoot ratios were different between species and different water availability. The root-shoot ratios of *T. ramosissima* seedling were greater than one under all measured water availability conditions. This agrees with the findings in Wang's experiment[15], which found that the root-shoot ratio of four Changbai Mountain broadleaf forest species was also bigger than 1 under drought conditions. It indicated that due to the high speed growth of *T. ramosissima* seedling roots, the below-ground section competed photosynthetic material excessively with the above-ground one, and thus reduced the distributive ratio of above-ground section's carbohydrate, and affected the growth of the above-ground section[16]; but the root-shoot ratio of *H. ammodendron* seedlings was smaller than one under every water supply condition. It demonstrated that the carbohydrate distribution ratio of *H. ammodendron* seedlings in the belowground and above-ground sections was basically similar. This also was the reason why the above-ground section of *H. ammodendron* seedlings was more robust than *T. ramosissima* seedlings under the same water supply conditions, which agreed with the former results.

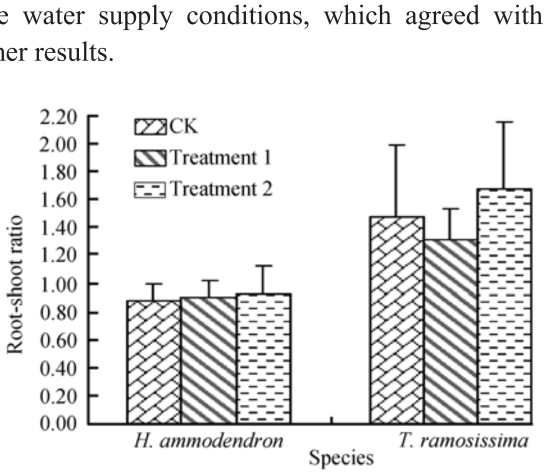

Figure 5 Effect of water availability on the root-shoot ratio of the study species.

The growth proportions of above-ground and below-ground sections were basically similar under normal water availability conditions[17]; the change of biomass distribution provides an adaptation to the environment's change with decreasing water supply[5]. General research shows that the increase of root-shoot ratio enlarges the absorbed quantity of water and nutrients, and enhances the ability of plant to resist drought and infertility, and it plays an important role in plant adaptation to harsh environments [16]. Compared with CK, both the root-shoot ratios of *H. ammodendron* seedlings increased slightly under treatment 1 and 2, but was not significantly different. The root-shoot ratio of *T. ramosissima* seedlings also showed an increased under treatment 2, but decreased under treatment 1. Compared with CK, analysis of variance with the two other treatments showed no significant difference. These demonstrated that the two species have some self-protection ability. With decreasing water supply, their photosynthetic materials were transferred to the belowground portions of the plant, and increased the plant's competitiveness, thus preserving the individual plant's nutrients and water acquiring ability. This agrees with the findings of Zhang et al. [18] who studied phenotypic plasticity in response to the heterogeneous water supply in rhizomatous grass species, *Calamagrostis epigejos* in the Mu Us Sandy Land of China, and also agreed with the result of increased root-shoot ratio as shown in the increasing drought-resistance of *Chilopsis Linearis*[5], *Glycyrr hiza uralensis Fisch*[19] and *Elaeagnus mooceroftii Wall ex Schlecht*[20].

3 Conclusions and discussions

3.1 The impact of water availability on root growth and biomass allocation of shelterbelt vegetation seedlings

The response of plants to the environmental conditions, especially to the water availability, occurs primarily through the root system. The interaction between soil and root is a complex physiological and ecological process. During this process, plants adapt to changed conditions in the environment. In order to improve the competitive efficiency, including absorption of nutrients and water, plant roots obviously show plasticity[21,22]. Root depth of plants of *H. ammodendron* and *T. rarnosissima* exhibited an increasing tendency with a decrease of water supply in the shelterbelt along the Tarim Desert Highway. And in treatment 2, the root vertical depth of *H. ammodendron* seedlings was significantly greater than that of CK. Both plants species adapt to the reduction of the water supply by exhibiting root elongation. Yu et al.[5] found similar results in his study which showed that the root length of *Chilopsis linearis* increases with an increase of water stress. Our results indicated that, when available soil moisture in root area decreases, plants will initially allocate more photosynthetic organic substances to roots in order to accelerate the growth of roots, which will allow roots to extend to more water-rich areas, expanding water adsorption and enhancing the plant's competitiveness. In both treatments when compared with CK the underground biomass of two plant species seedlings showed an increasing trend. *H. ammodendron* had the greatest biomass in treatment 2, but *T. rarnosissima* had greater biomass in treatment 1. Evidently, *H. ammodendron* seedlings were better adapted to treatment 2, while *T. rarnosissima* seedlings were better adapted to treatment 1, which was consistent with Wang's[15] results, who found that root biomass of *Quercus mongolica* increased with the reduction of soil moisture. We concluded that the two plants specie shows a relatively strong drought-resistant characteristic. The root response to a deficiency of soil water benefits the plant by increasing the root's ability to absorb water and nutrients to provide for the plant's needs[23].

3.2 The impact of water availability on fine root biomass allocation in shelterbelt vegetation seedlings

Fine roots actively adsorb water and are the most important part of a plant in water absorption. When the soil moisture condition changed, changes in the growth and distribution of the fine roots can reflect the vitality and adaptability of plant roots to some extent[1]. Even though fine roots are low in proportion to the entire plant's biomass in deep soil, these fine roots play a very important role in plant water absorption[24−26]. The fine root biomass of two kinds of species in the shelterbelt along the Tarim Desert Highway under the two treatments were both higher than CK, that means the two species' seedlings can adapt to reduced water availability by increasing their fine root biomass. The fine root biomass in deep soil (>60 cm) was analyzed under different water availability conditions. The results showed that the fine root biomass of plants in deep soil (>60 cm) of the shelterbelt along the Tarim Desert Highway under treatment 2 was significantly higher than under CK and treatment 1. Liu et al.[1] obtained similar results while studying dry season biomass of *Artemisia halodendron*; they found a larger proportion of fine root biomass of *A. halodendron* in deep soil in a moving sand dune when compared to fine root biomass in a fixed sand dune. Persson et al.[27] obtained similar results in their study of *Picea abies* (L.) Karst. under drought environments. This species also developed the fine roots in deep soil, with a larger proportion of fine roots in deep soil. We conclude that shelterbelt plants compensated for the soil moisture deficit by the elongation growth of the fine roots in order to expand its own space to supplement the nutrition in the extremely arid hinterland of the Taklimakan Desert, which is also decided by hydrotropism of roots. Shelterbelt plants increased their deep fine root biomass to adapt to lower water availability. At the same time, probably due to a hydraulic upgrade function[28], the development of deep root system will be beneficial to effective use of the deep soil moisture.

3.3 Effects of water availability on root-shoot ratios in shelterbelt plants

The root-shoot ratio in plants reflects many internal basic changes and the process of self-adaptation and self-adjustment under the effect of environment factors[29]. It is a manifestation of a photosynthetic material allocation relationship between above-ground and underground biomass, and it is an important index to study how plants can adapt to the environment. Our research indicates that the root-shoot ratio of the two experimental species in the shelterbelt along the Tarim Desert Highway displayed heterogeneity. This heterogeneous reaction under different conditions was different in plant response, which varied by species and water availability. It fully explains how different species have different root-shoot ratios and how the root-shoot ratio of the same species changes in the microenvironment. This difference reflects the difference in each species adaptability to the environment. First, the root-shoot ratio of *H. ammodendron* seedlings in the shelterbelt along the Tarim Desert Highway was smaller than 1, while *T. ramosissim* seedling's was bigger than 1. This result shows that the growth of below/above-ground section of *H. ammodendron* seedlings was relatively coordinate, which satisfied the balance supplement for energy and substances. But the rapid root growth of *T. ramosissima* seedlings exceeded that of *H. ammodendron* seedlings. This rapid root growth restrains the growth of above-ground section, thus making the root-shoot ratio relatively large. Secondly, under conditions of lower water availability, the root-shoot ratio of *H. ammodendron* seedlings increased. This agreed with Jing et al.[30], who studied similar variation in some Ginkgo family plants under different soil water availability conditions. It also agreed with the findings of a study on *Cunning hamialaneolata* in which the photosynthetic material of *C. hamialaneolata* seedlings was committed to the below-ground section of this plant under water stress, especially to the fine roots, and resulted in an increased proportion of the plant allocated to the belowground section; this changed the allocatation structure of photosynthetic material and increased the root-shoot ratio[31]. But the root-shoot ratio of *T. ramosissima* seedlings of treatment 1 and CK was smaller than under treatment 2, This indicated that more energy and substances were thrown into roots due to the decrease of water availability, thereby making fewer photosynthetic resources available for the above-ground nutrient organs of the plant. This biomass allocation reflects that these plants can use this survival strategy to some extent under stressful environmental conditions. Meanwhile, it shows that the increase of the root-shoot ratio can mitigate the conditions when a plant's supply is lower nutrients and water[23].

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